Optoelectronics properties of Silicon photodiodes.

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ABSTRACT.

To measure a photodiode reflectance, the reference detector is placed first at position A and its reading is recorded. Afterward the photodiode to be tested is introduced in the laser beam at half way between the shutter and position A, with an angle of incidence about 3º and the reference photodiode is moved to position B and its response recorded. Then the reflectance is given by the ratio between the reference detector reading at position B and the reading at position A. Placing the photodiode to be tested a that position assures that the beam seen by the reference detector runs the same distance in both cases, avoiding errors associated to the divergence of the laser beam. A 3º incidence angle is small enough so that the measured reflectance is considered as the normal incidence reflectance. Finally, just to remark that the reference detector is placed at normal incidence any time.By this method the spectral reflectance of one set of photodiodes from the same manufacturer and batch and another set of three photodiodes (from the same manufacturer) used to maintain the spectral responsivity scale at the Institute for Applied Physics (CSIC) has been measured at wavelengths: 441.8 nm (He-Cd), 568.2 nm (Kr), 632.8 nm (He-Ne) and 647.1 nm (Kr). A typical uncertainty value for this kind of measurement in this laboratory is 0.15 %, which is determined mainly by the measurement repeatability and the linearity of the reference detector and its associated electronics. Just for identification purposes, the model of all photodiodes studied is S1337-1010BQ. In this work we present the analysis spectral reflectance of silicon photodiodes.

INTRODUCTION.

Silicon photodiodes are more sensitive and quicker than thermal detectors. For these reasons silicon photodiodes are used to maintain scales of spectral responsivity in the spectral range (300 nm – 1000 nm) in many National Laboratories [1, 2, 3, 4, 5].The spectral responsivity of a photodiode depends on the reflectance and the internal quantum efficiency, so a good approach to determine responsivity is to know both reflectance and internal quantum efficiency. Because of that, in this work we present a study about the reflectance of silicon photodiodes, with two goals: To study the variability of reflectance among photodiodes from a single batch, and to study the reflectance ageing of some silicon photodiodes used as standards during six years. In some radiometric applications, the reflectance of individual photodiodes plays an important role because they have to match to a pair or minimized or maximized, as it is the case for silicon trap radiometers [6, 7]. The ageing of silicon photodiodes has been studied for several authors and all them looked at the stability of the internal quantum efficiency [8, 9] rather than to the reflectance.

To approach the first objective, we restricted the study to a single manufacturer, because the reflectance is linked to the structure and thickness of the passivation layer. We chose photodiodes from Hamamatsu, because they are the most stable and used in many National Laboratories.

Furthermore we have used photodiodes from just one batch to avoid as much as possible changes in the oxide thickness which in turn produces different reflectance values.To achieve the second goal, the ageing of photodiodes, we have measured the reflectance of three silicon photodiodes, from the same manufacturer, that are used to maintain the scale of spectral responsivity of Institute for Applied Physics (CSIC).

FUNDAMENTALS.

When the radiation impinges on a detector different physical process happen. Part of incident radiation is reflected by the sensitive surface, the rest pass to the interior of detector, where can be partially or totally absorbed. The response of the photodetector is related to the amount of absorbed power, but for evaluating the incident power is necessary to know the absorbed, the reflected and the transmitted ones.If the photodiode's response to optical radiation is its short circuit current, the total photodiode response can be written as:

$$I = \left(1-\rho(\lambda)\right)\eta(\lambda)\frac{\lambda q}{hc}\phi \qquad (1)$$

Where I_0 is the dark current, $\eta(\lambda)$ is the internal quantum efficiency, which indicates the number of electrons produced by each absorbed photon, q is the electrical charge of the electron, h is the Planck constant , c is the light velocity , ϕ is the radiant flux, λ is the wavelength and $\rho(\lambda)$ is the photodiode's reflectance. From equation (1) the responsivity can be obtained as:

$$R = \frac{I - I_0}{\phi} = \left(1-\rho(\lambda)\right)\eta(\lambda)\frac{\lambda q}{hc} \qquad (2)$$

This equation tells us that the responsivity depends on the wavelength of the incident radiation, directly and via the reflectance of the surface and the quantum efficiency. Then, the responsivity will be known if the reflectance and internal quantum efficiency are known at every wavelength. For this reason, the measurement of the photodiodes' reflectance is presented in this work as a previous step to know the responsivity. Looking at equation 2 and bearing in mind the layered structure of silicon photodiodes and the high refraction index values, it is noticeable to remark that photodiode's response notably depends on the angle of incidence and the polarization state of the incoming radiation [6,7,10].

EXPERIMENTAL PROCEDURE.

To measure the photodiodes´ reflectance we have arranged an experimental setup as shown in figure 1. Kripton, He-Ne and He-Cd lasers have been used in this setup as radiation (sources).

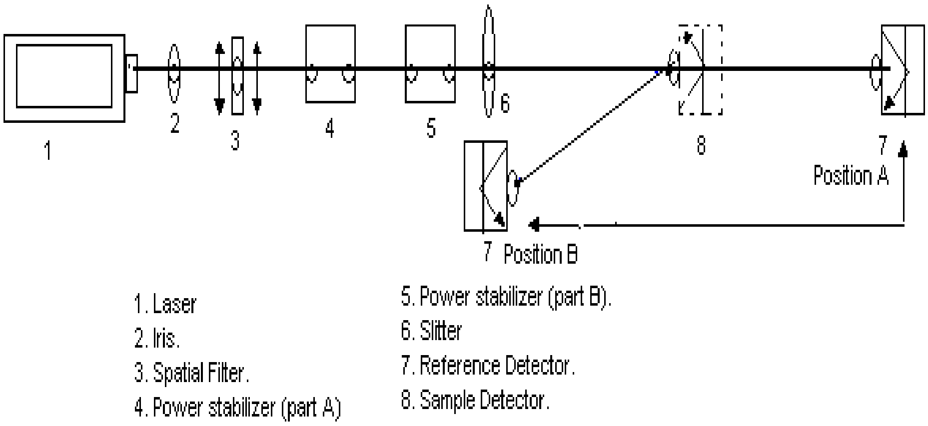

Figure 1. Experimental setup for measuring reflectance.

The linearly polarized laser beam is spatially filtered and power stabilized .Afterward the beam goes through a shutter that can be controlled via a PC (Personal Computer). The shutter is used to block the laser beam to measure the photodiode dark response that is subtracted to every photodiode's reading. Placing a photodiode in position A, the incident power is recorded.To measure the power reflected by the photodiode to be tested, we introduce it in the laser beam with an angle of incidence about 3º and move the reference photodiode to position B.Let remark that the photodiode to be tested is half way between the shutter and position A of the reference detector, so that the beam seen by the reference detector runs the same way in both cases, assuming specular reflection at the photodiode's front surface. Furthermore, the reference detector is used at normal incidence in both cases. It is important that the incidence angle over the sample photodiode be small, because the reflectance changes with the incidence angle, as mentioned before. If we make the ratio between the signal of the reference detector in position B (reflected power) and the signal in position A (incident power) we will get the spectral reflectance of the photodiode under test. By this method we have measured the spectral reflectance of one set of ten photodiodes from the same manufacturer and batch and another set of three photodiodes (from the same manufacturer) used to maintain the spectral responsivity scale at the Institute for Applied Physics (CSIC).Measurements were done at wavelengths: 441.8 nm (He-Cd), 568.2 nm (Kr), 632.8 nm (He-Ne) and 647.1 nm (Kr). A typical uncertainty value for this kind of measurement in this laboratory is 0.15 % [1].

RESULTS AND DISCUSSION.

Figure 2 shows the reflectance measured for photodiodes 1 to 5. Photodiode 1 and 2 have almost the same behavior, and something similar happens with photodiodes 3 and 4. Only number 5 seem to behave in a more different way.

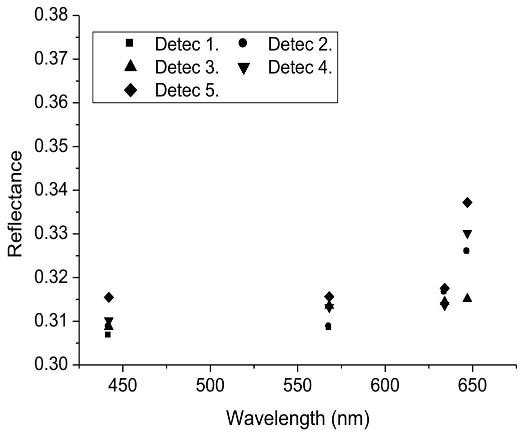

Figure 2. Measured reflectance of photodiodes 1 to 5.

Reflectance values measured for photodiodes 6 to 10 are shown in Figure 3. Photodiodes 7, 8 and 9 have almost the same behavior up to the wavelength of 632.8 nm from which they differentiates.

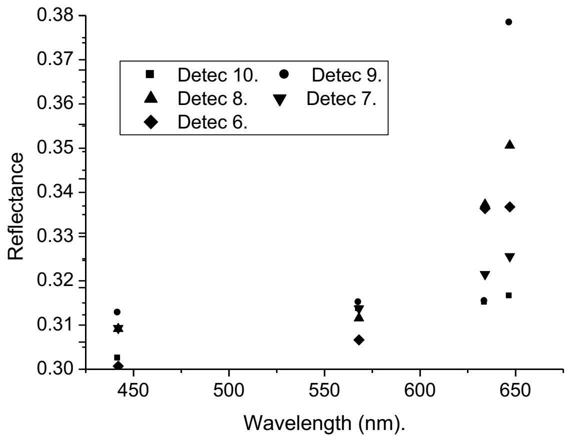

Figure 3. Measured reflectance of photodiodes 6 to 10.

In general spectral reflectance values of all the photodiodes studied are closer in the range (441.8 nm - 632.8 nm). Quantitatively, the maximum difference is about 3 % at 441.8 nm and about 7 % at 647.1 nm. The second goal of this work was to study ageing effect over the reflectance of silicon photodiodes used to maintain responsivity scales.

Figure 4 shows the reflectance values measured in this work for standard detectors Ciri, Dss01 and Dss02, whose spectral responsivity was calibrated six years ago for the first time.

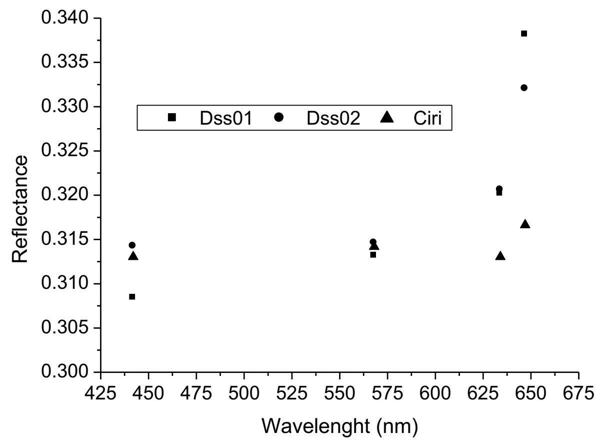

Figure 4. Measured reflectance of standard detectors.

Difference between the old spectral reflectance values and the present ones, for these photodiodes can be seen in Figure 5.

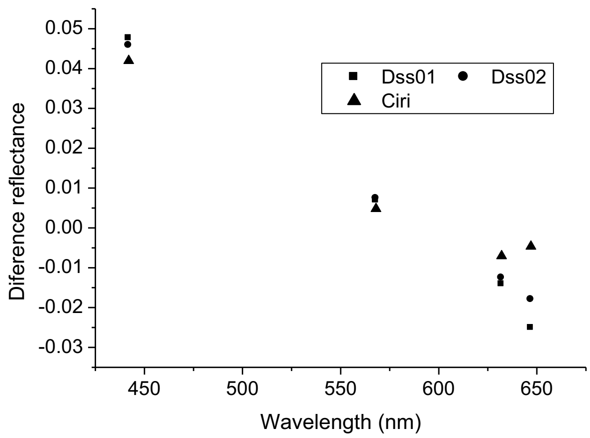

Figure 5. Difference between previous spectral reflectance values and this work values.

It can be observed the same tendency for the three photodiodes: at short wavelength the reflectance difference is positive; i.e. the photodiode's reflectance has decreased, while at long wavelengths the reflectance difference is negative, which means that the photodiode reflectance has increased.Furthermore, the relative spectral reflectance change is larger at short wavelengths (5%) than at long wavelengths. It also seems that the tendency is spectrally monotonous.

If it is assumed that the change in reflectance is related just to a thickness change of the silicon oxide passivation layer [5,7,11], it would be needed an increase of about 2 nm over 30 nm, approximately, to be able to explain such a change. This type of change in the silicon oxide layer has not been referred in the literature (up to the knowledge of the authors) and it is not likely to be produced since the detectors have always been kept at room temperature in dry environments. Therefore another mechanism must be likely responsible for this behavior.

CONCLUSIONS

At present state of the art of technology, reflectance of silicon photodiodes changes from item to item within the same batch. Therefore in high accuracy applications where the reflectance plays an important role as in the case of trap detectors for radiometric measurements, it is necessary to measure the reflectance of single elements to select them for matching or minimum reflectance.

Ageing of silicon photodiodes is not only related to internal quantum efficiency as it has been considered by other authors, but to spectral reflectance changes too as it has been shown in this work.

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